FAST BEAM DEFLECTION FOR MITIGATION OF PARAMETRIC INSTABILITY

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MARGHERITA TURCONI

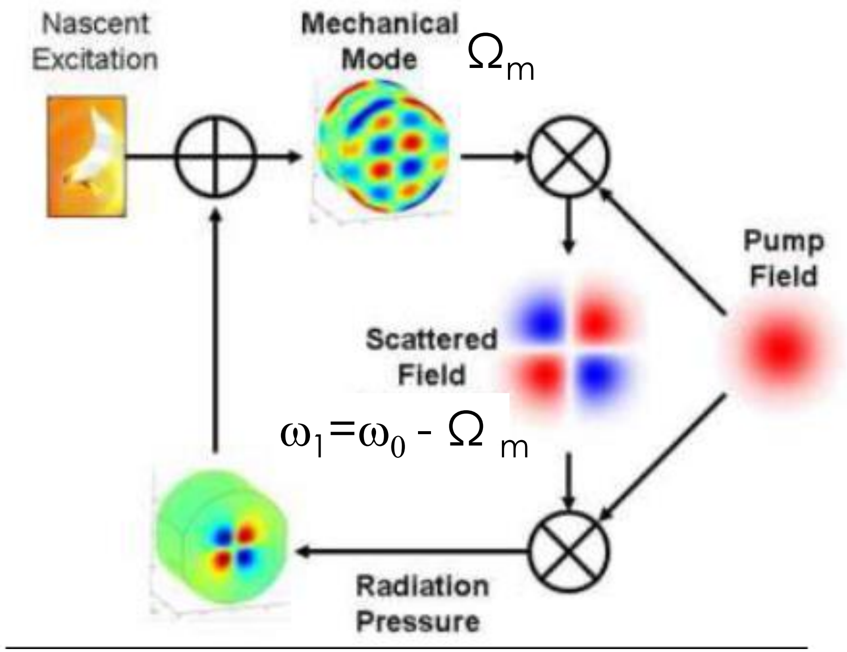
THOMAS HARDER, REMI SOULARD, WALID CHAIBI

Outline

- Introduction:
  - Parametric instability (PI), PI Mitigation strategies.
- PI mitigation by radiation pressure
- 2D fast beam deflection
- Conclusion
- Perspectives

Introduction
PI: 3 mode instability

- Where? In optical cavities (optomechanical systems)



Cavity fundamental mode ω_0

Evans et al, Phys. Lett. A, 374(4), 665-671 (2010)

if

- ω_0 and ω_1 resonant in the cavity
- Matching between mechanical and optical mode shapes

→ Growing amplitude of Ω_m and ω_1

Introduction

PI: parametric gain

Mirror Quality Factor

Power in the cavity

Geometrical Overlap coeficient With the n^{th} optical Mode

$$\text{Gain } R_m = \frac{8\pi Q_m P_{\mathrm{arm}}}{M\, \Omega_m^2\, c\,\lambda} \sum^{\infty} \Re[G_{\mathrm{cav}}] B^2_{m,n}$$

Mirror Mass

Mechanical frequency

Sum over all optical modes

Instability: R > 1

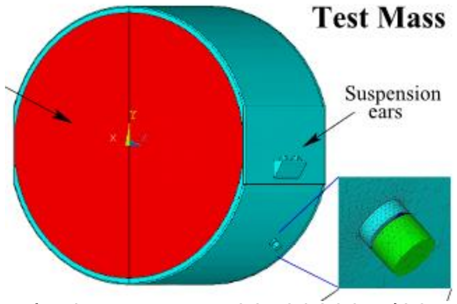
PI Rise time: $\tau_{PI} = \frac{2Q_m}{\Omega_m (R_m - 1)}$

[Braginsky e

[Evans et al, P

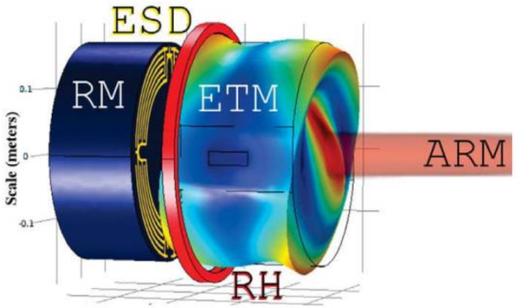
Introduction
PI Mitigation strategies

Passive methods:
- Thermal tuning (changing radius of curvature)
- Acoustic Mode Dampers (changing Q of mechanical modes)



S. Gras et al, Phys. Rev. D 92, 082001 (2015)
S. Biscans et al. Phys. Rev. D. 100, 122003 (2019)

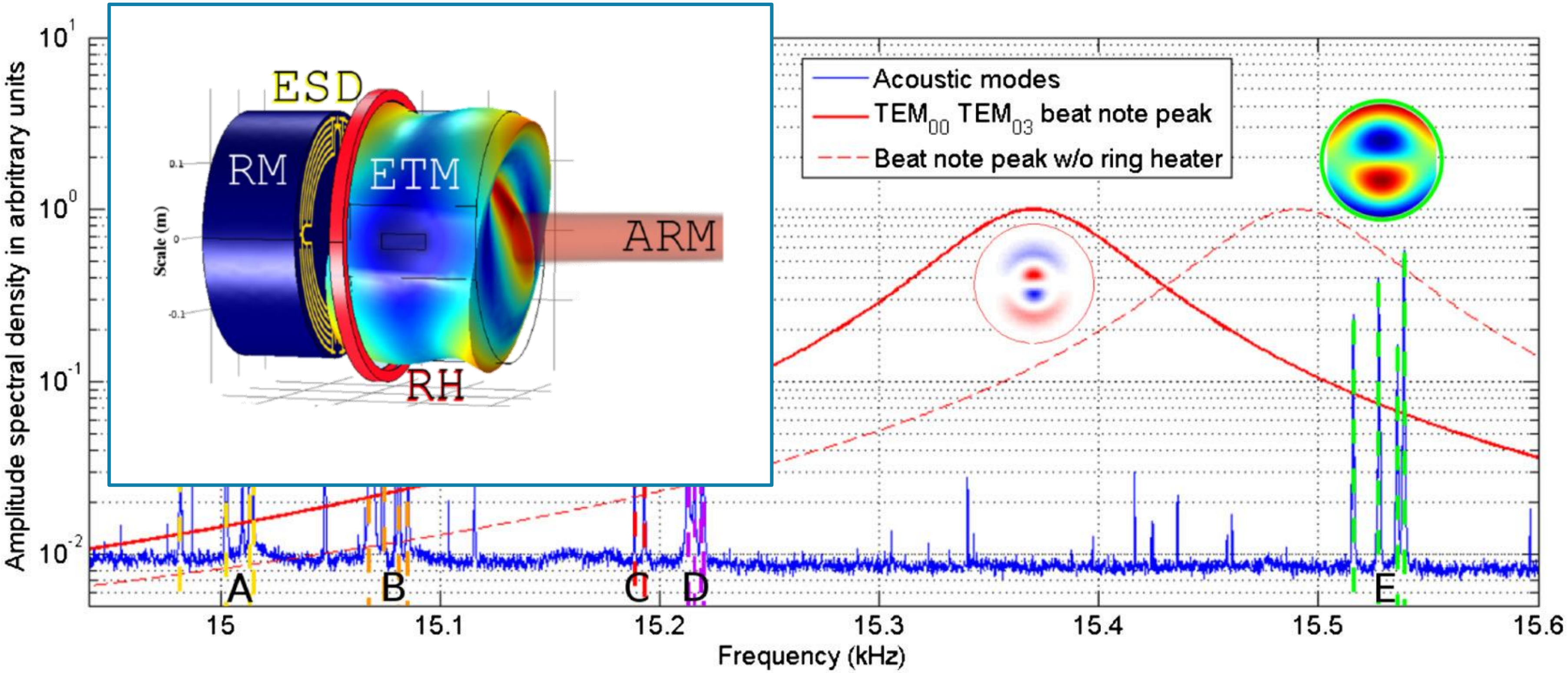
Active methods:
- Electrostatic actuators



C. Blair, et al, Phys. Rev. Lett. 118, 151102 (2017))

Introduction
PI Mitigation: thermal tuning

PI observed in LIGO (O1)

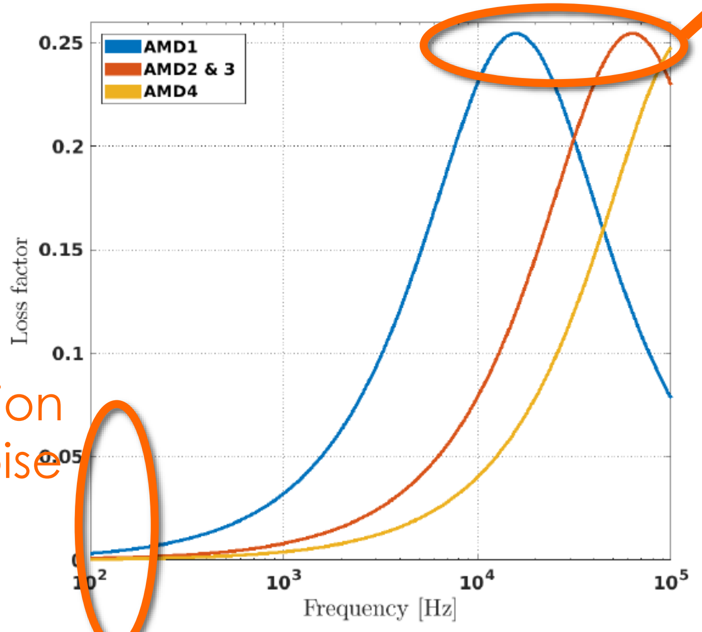


O1: LIGO observed PI at 50kW, thanks to this technique the intracavity power was increased to 100 kHz

Introduction

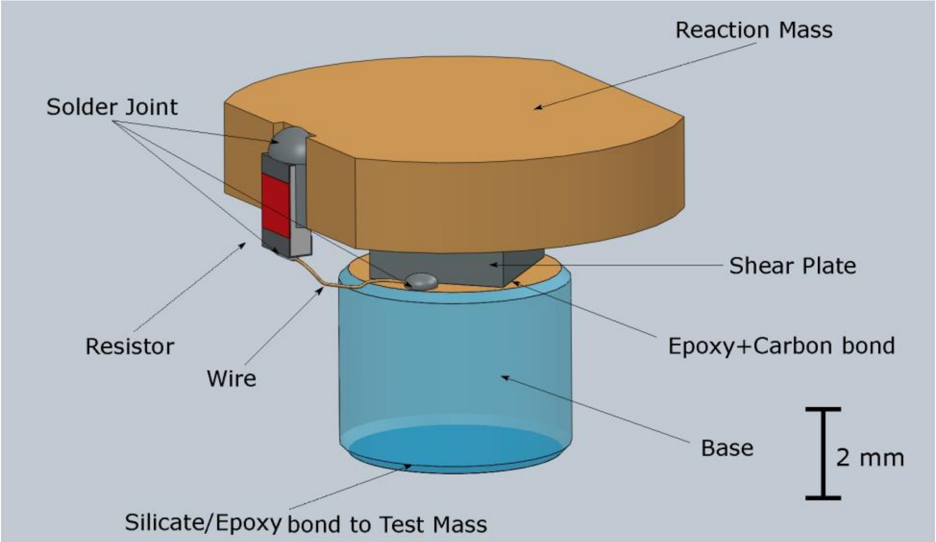
PI Mitigation: Acoustic Mode Dampers(AMD)

25% loss factor



1% degradation of thermal noise

Piezo+ reaction mass

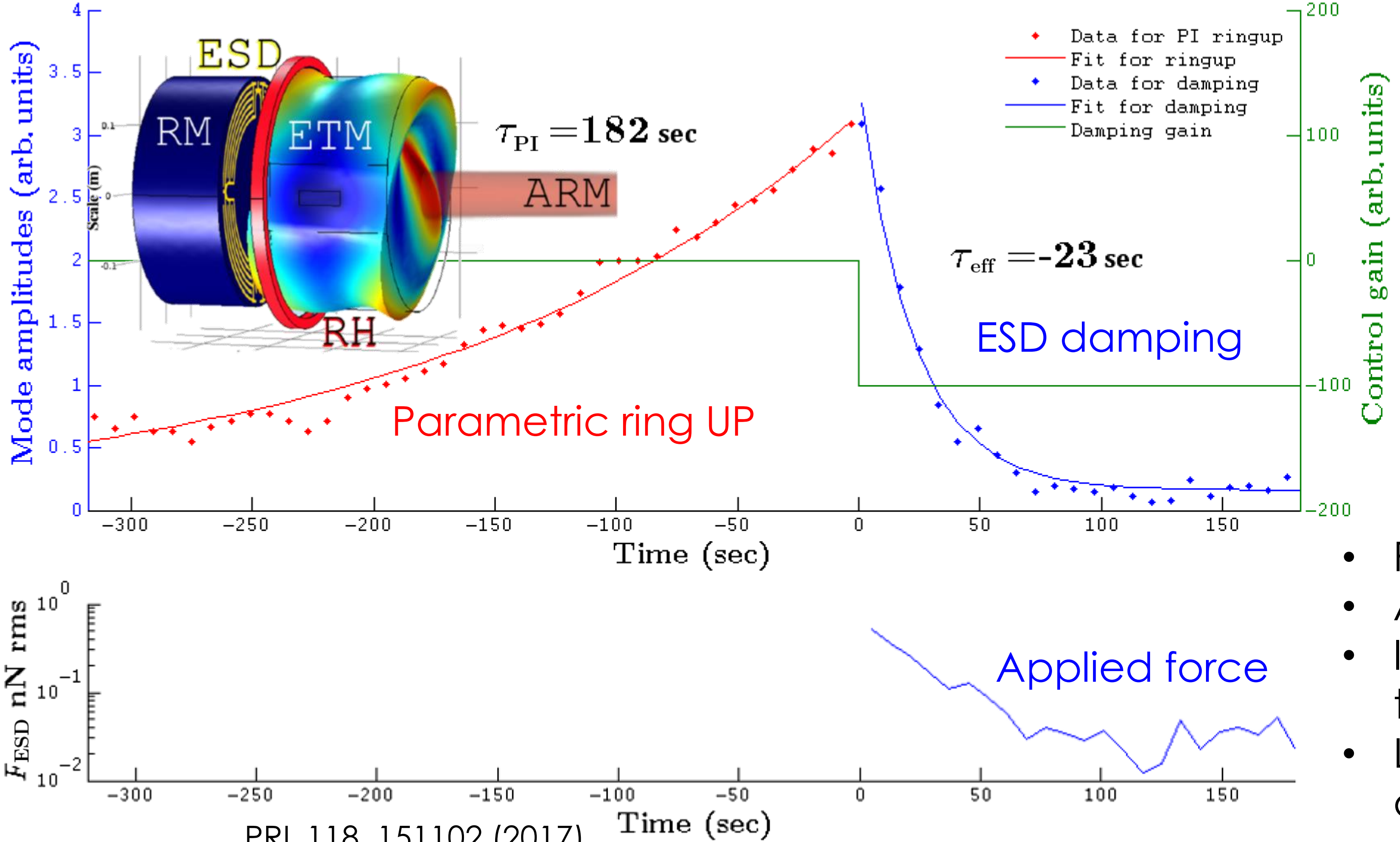


In 3rd generation detectors thermal noise contribution from dampers can be a significant issue.

[S. Biscans PhD Thesis 2018]

Introduction

PI Mitigation: Electrostatic actuators



PRL 118, 151102 (2017)

- Predicted force: 10 nN rms
- Actual force : 0.03 nN
- Insignificant noise contribution to interferometer output
- Limit: fixed position of actuators

Introduction
PI Mitigation strategies

Passive methods:

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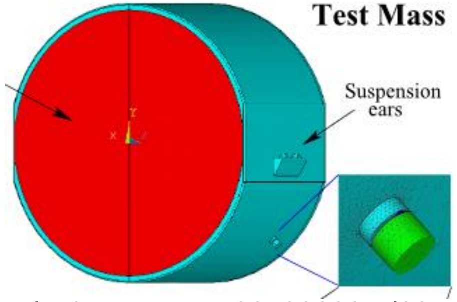

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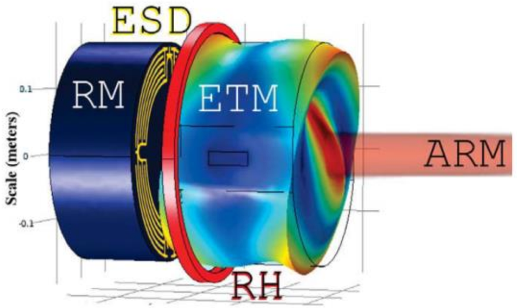
Active methods:

- Electrostatic actuators
- Damping system based on radiation pressure



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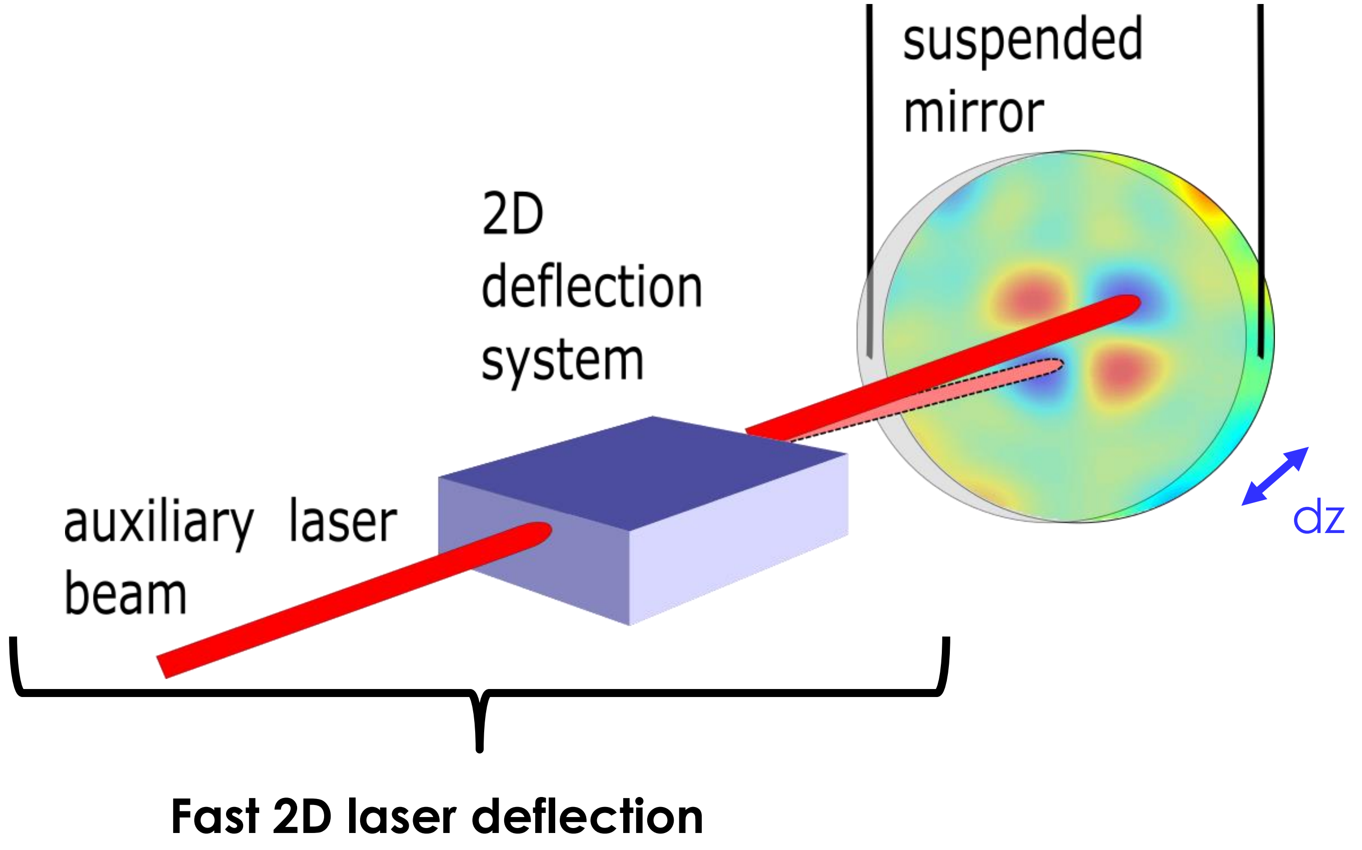
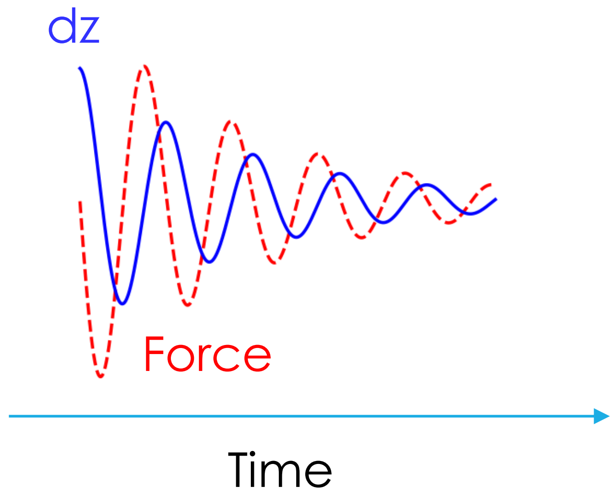
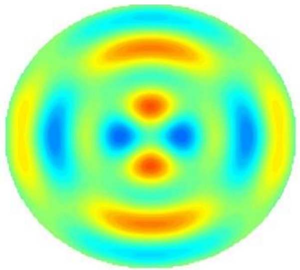
PI damping by radiation pressure





Fast 2D Laser deflection
Requirements

- Small ratio $\frac{beam\ divergence}{scan\ angle}$



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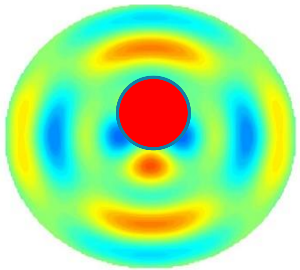

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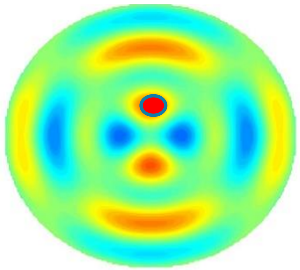

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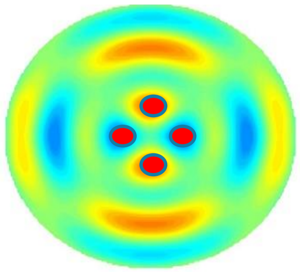

- Deflection in random access → optimal scan pattern

- High deflection rate: device able to damp mechanical mode up to few hundreds of kHz

Fast 2D Laser deflection
Requirements

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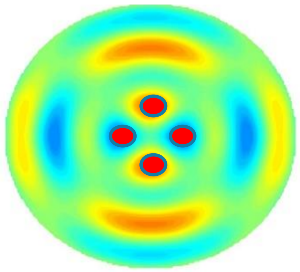
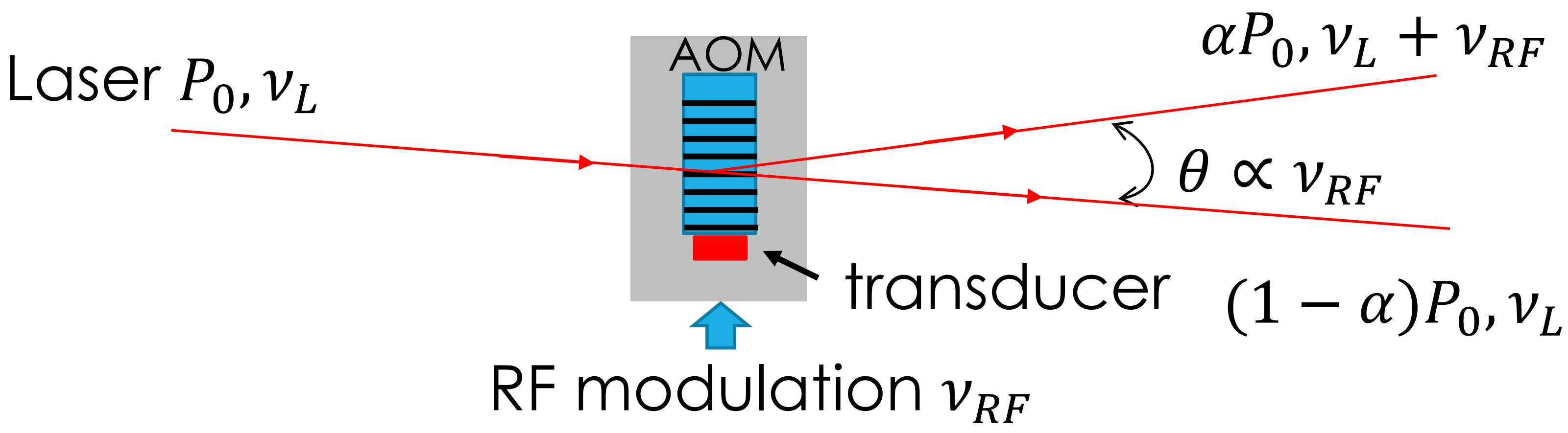


- Deflection in random access → optimal scan pattern
- High deflection rate: device able to damp mechanical mode up to few hundreds of kHz
- Radiation force of some nN rms → deflected beam of several W

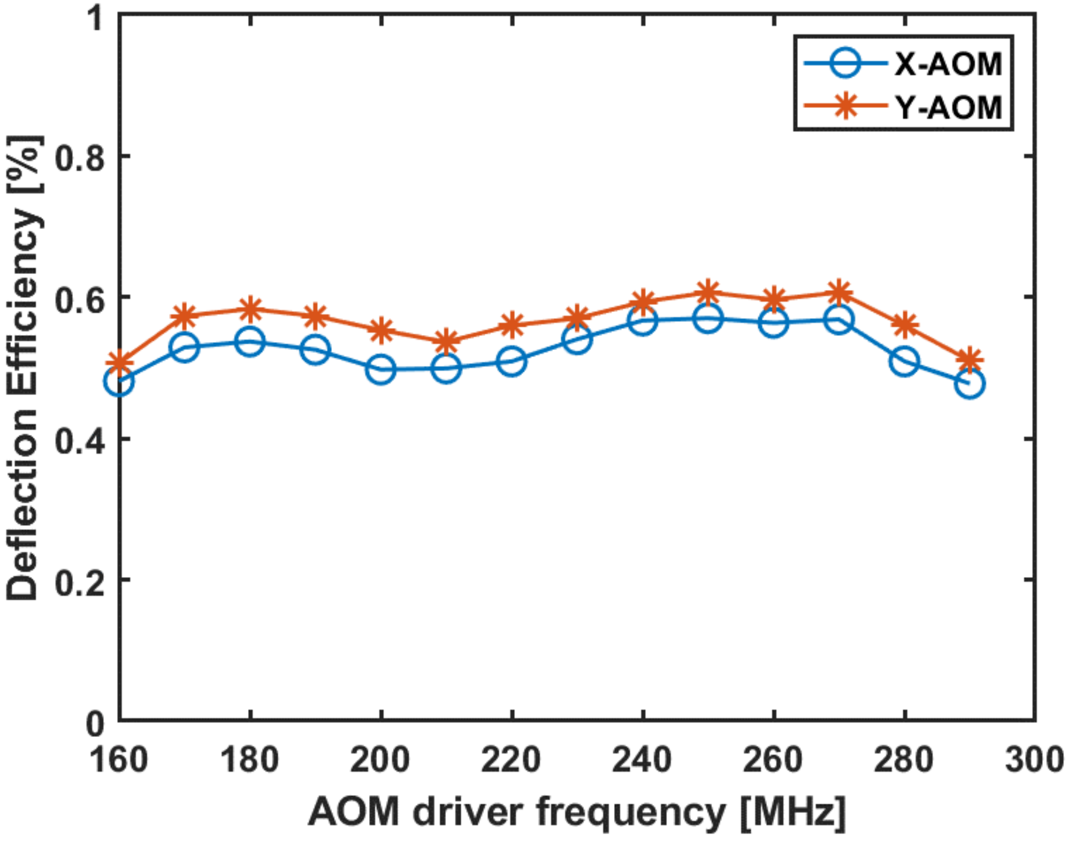
Fast 2D Laser deflection
AOM as deflector

→Diffraction of an electromagnetic wave by an acoustic wave



→ Chosen AOM has a rise time of 33 ns and θ_{max}= 34 mrad

Fast 2D Laser deflection
Deflection Efficiency of AOM

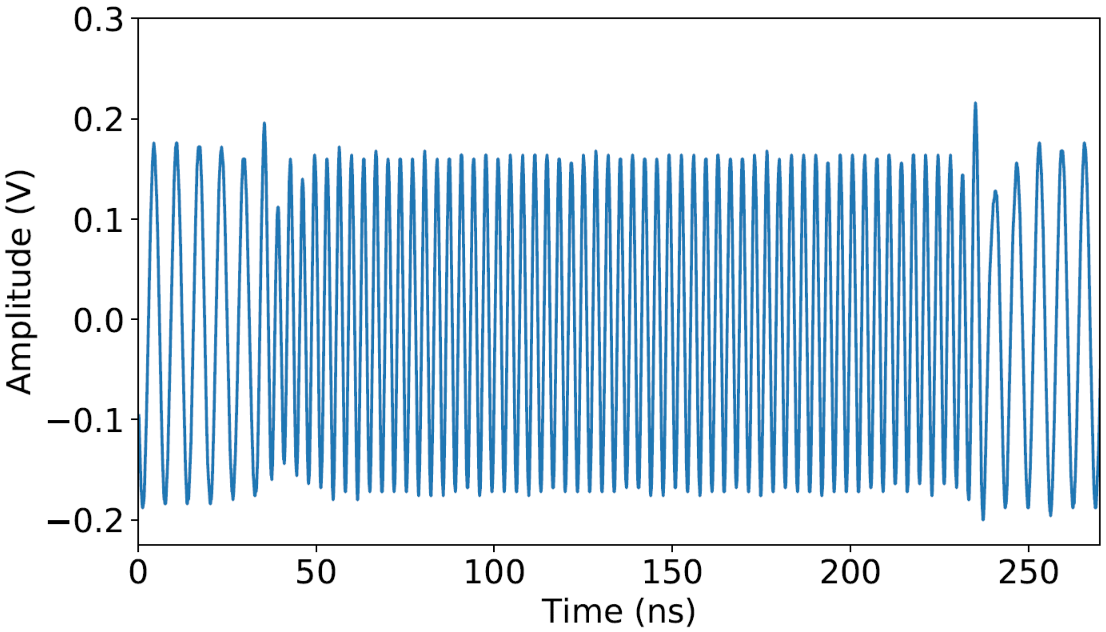


15 % flatness of the deflection curve

→ Amplitude of RF signals can be adjusted to control the deflection efficiency

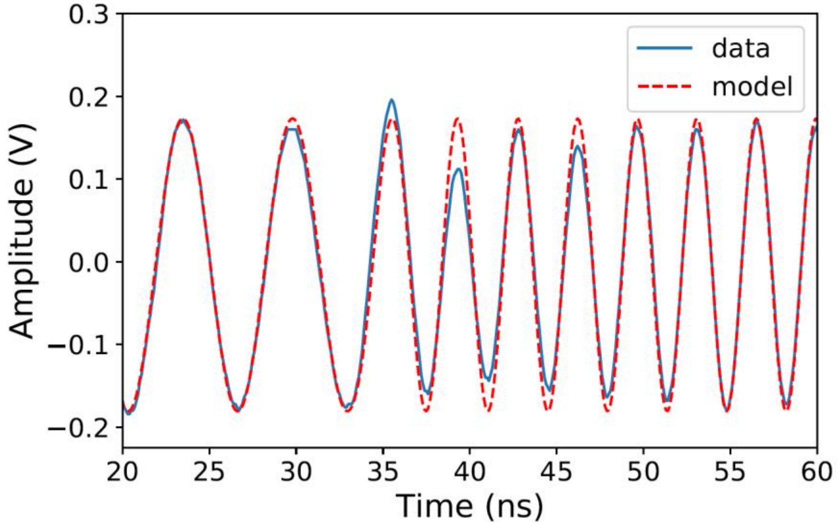
Fast 2D Laser deflection
RF driver: USRP

- **U**niversal **S**oftware **R**adio **P**eripheral **(**Software Defined Radio Reconfigurable Device**)**
- Controlled via a software on linux machine

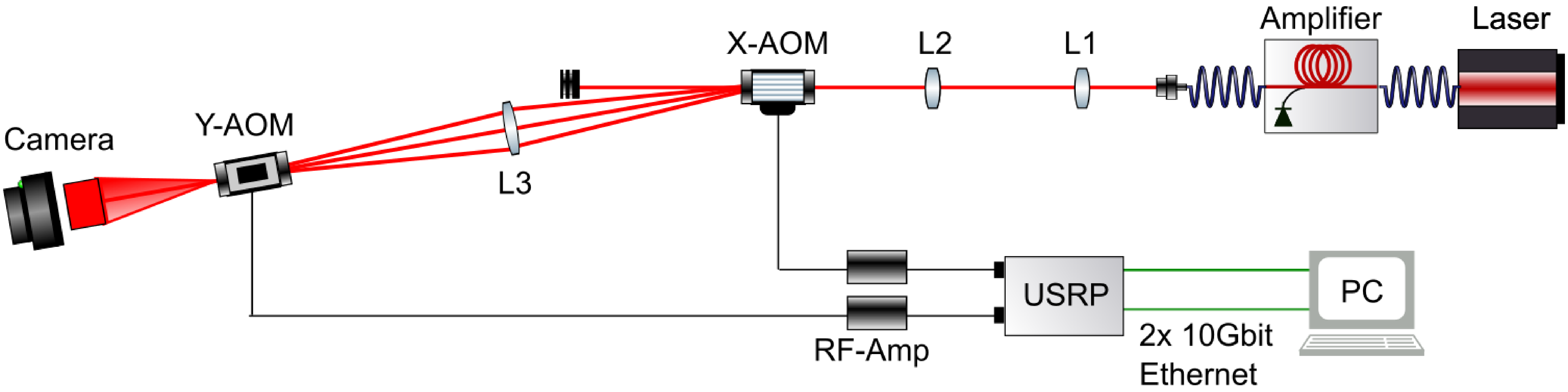


Fast 2D Laser deflection
RF driver: USRP

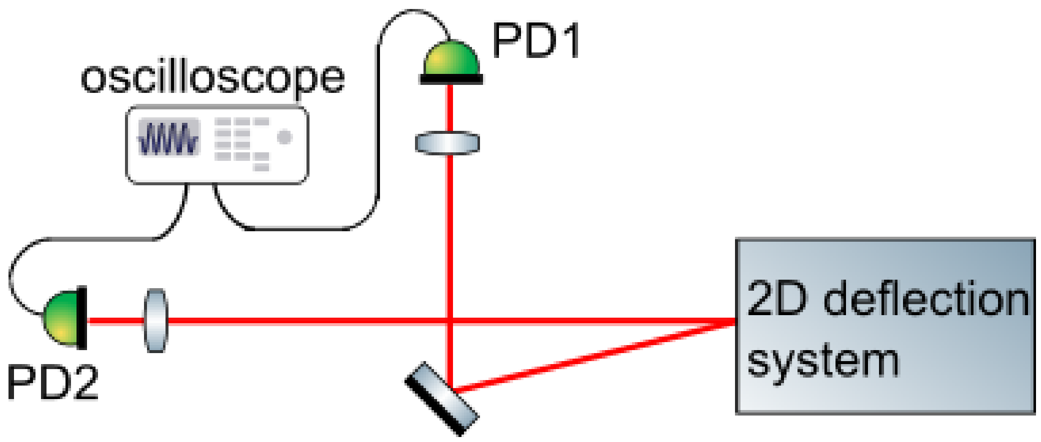
- **U**niversal **S**oftware **R**adio **P**eripheral **(**Software Defined Radio Reconfigurable Device**)**
- Controlled via a software on linux machine
- Frequency switch within ~2ns (exponential decay)

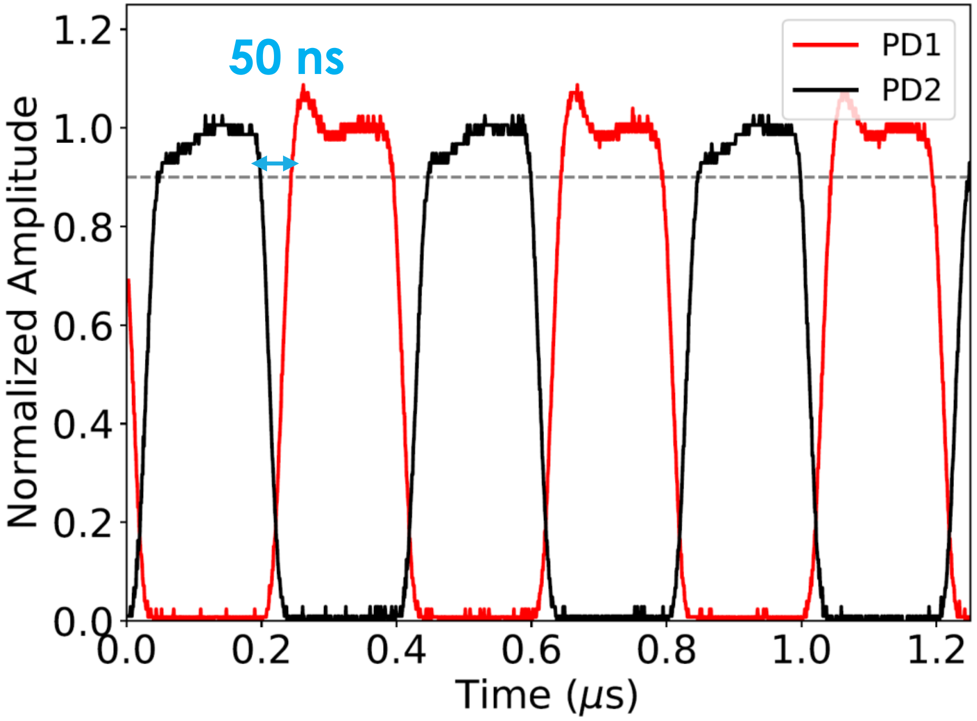


Fast 2D Laser deflection
Experimental setup



Fast 2D Laser deflection
Deflection transition time

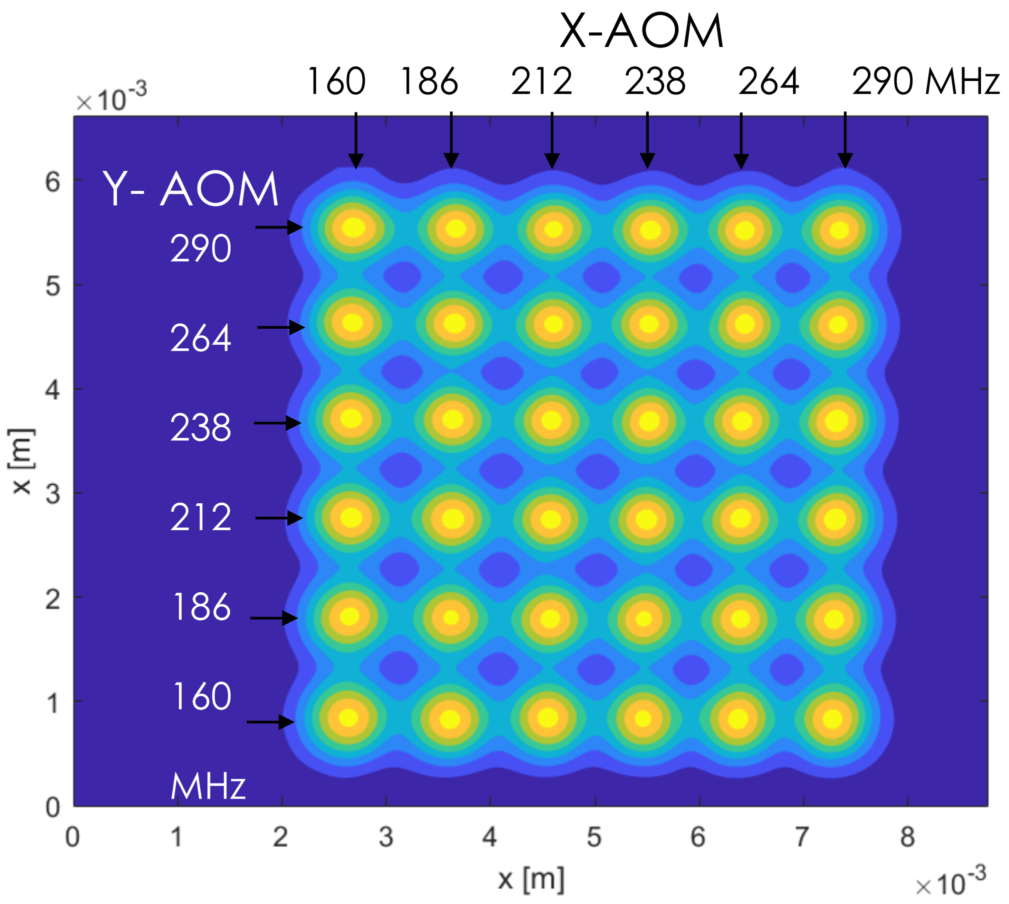




→ minimal transition time of 50ns between two arbitrary deflection spots

→ Result obtained with an input spot size of 200μm → $\frac{beam\ divergence}{scan\ angle} = \frac{1}{6}$

Fast 2D Laser deflection
Results

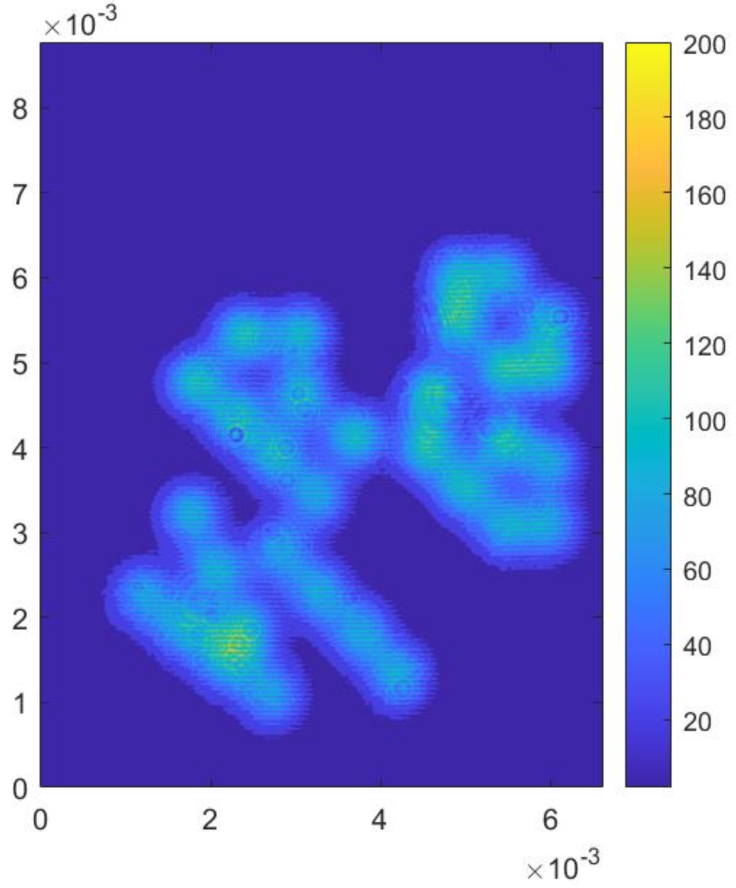


- RF power adjustment for homogeneous deflection power (~ 1%)
- 24,2% overall optical deflection efficiency
- Full scan angle of 34mrad

→ beam spot on mirror ~ $\frac{1}{6}$

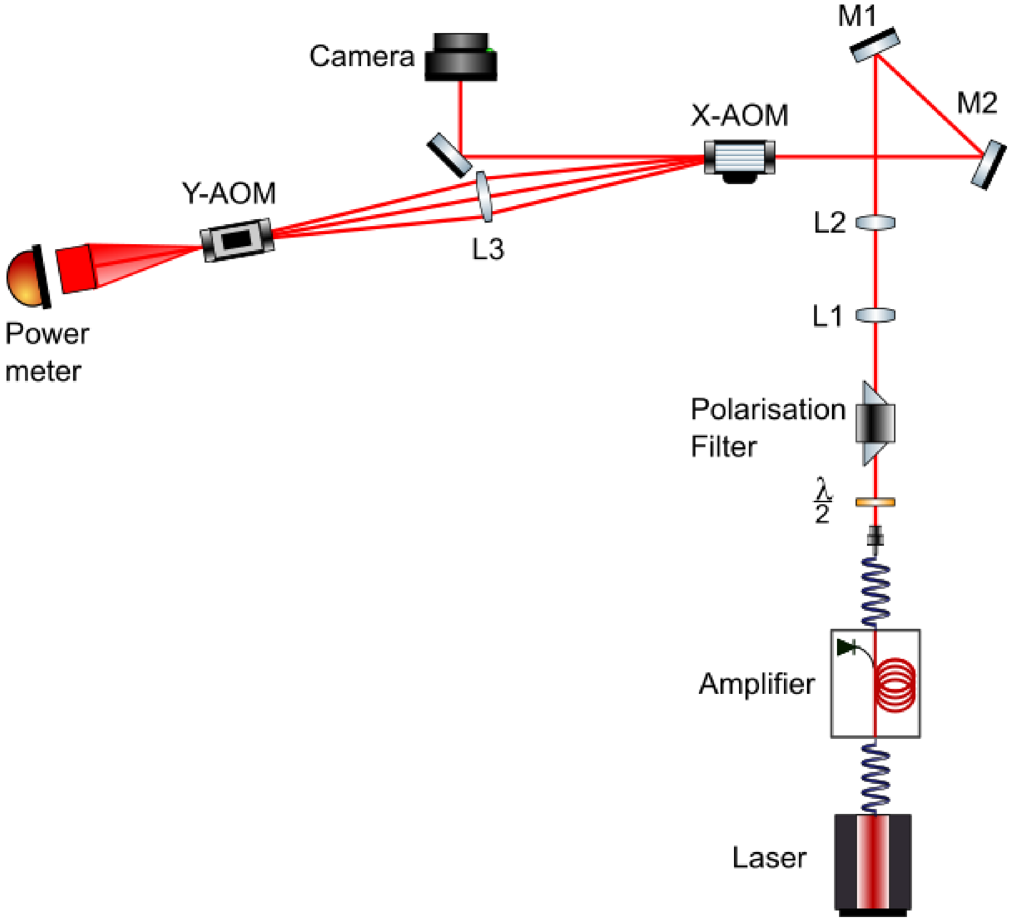
Fast 2D Laser deflection
Results

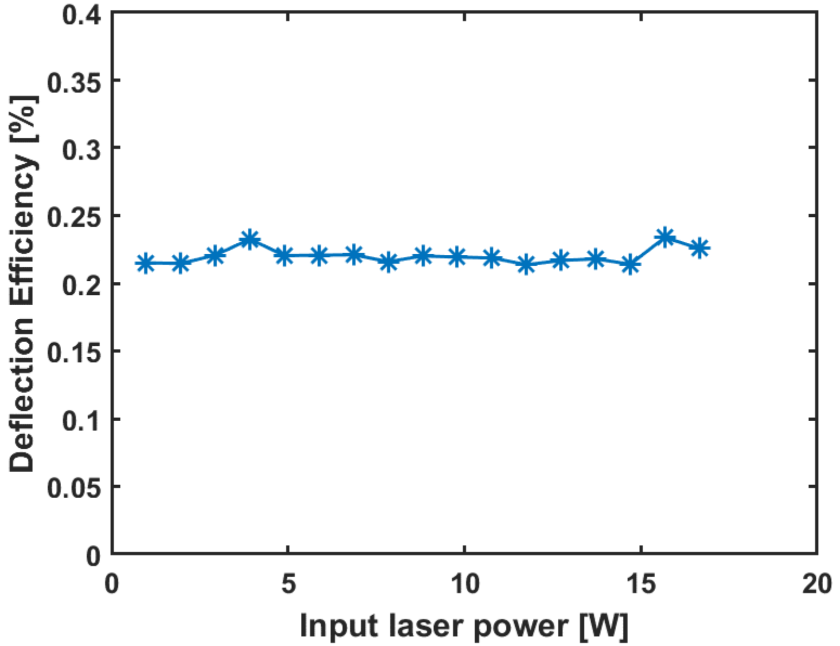
Camera 15cm after Deflector



scan on florescence card

Fast 2D Laser deflection
High Power Deflection



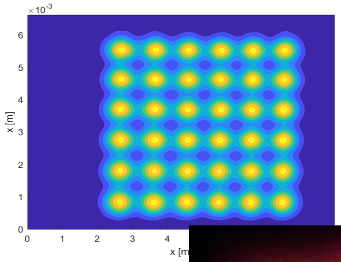


→ Maximal deflected beam of 3.6 W with 16.7 W input power

→ Observing Thermal lens on 0. order deflection

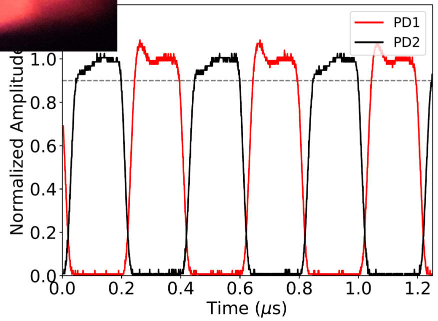
Conclusion
2D deflection system

- Small $\frac{beam\ divergence}{scan\ angle} = 1/6$



- Deflection in random access

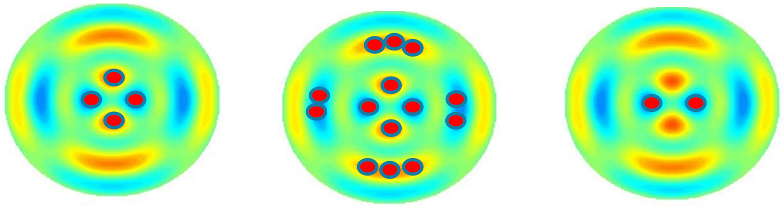
- High speed: deflection time= 50 ns

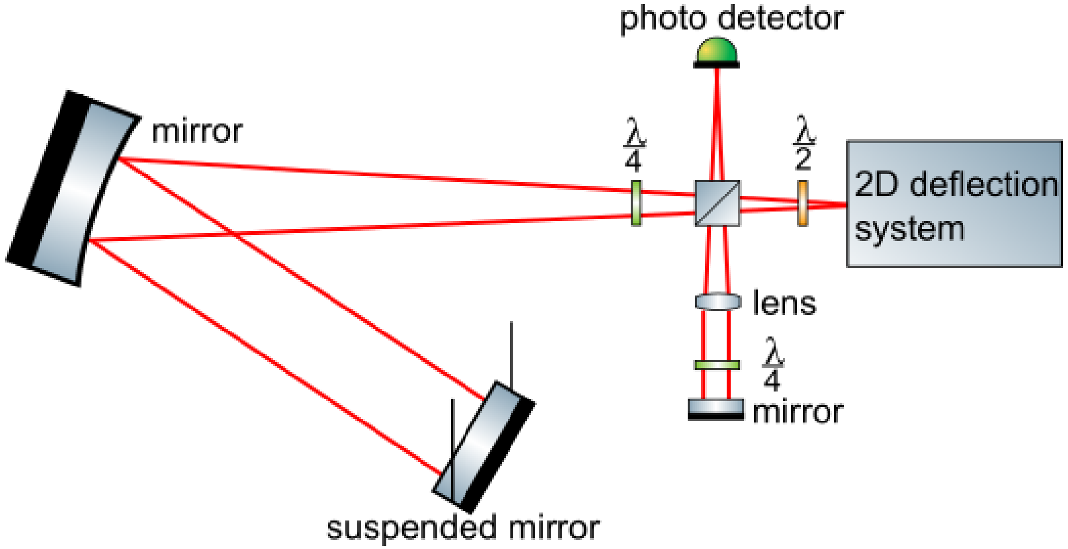


- High power deflected beam: 3,6 W→ 24 nN

Perspectives

- Use the 2D deflection device to detect the vibrations of a suspended mirror in a vacuum chamber → identification of the mechanical modes
- Test the device applying radiation pressure force to excite/damp a mechanical mode
- Optimize the efficiency (find best spatial and temporal overlap strategy)





- Implement power stabilization

Thank you for your attention